Integrating Soil Moisture and Evapotranspiration Data to Constrain Land-Atmospheric Water and Energy Balance Coupling

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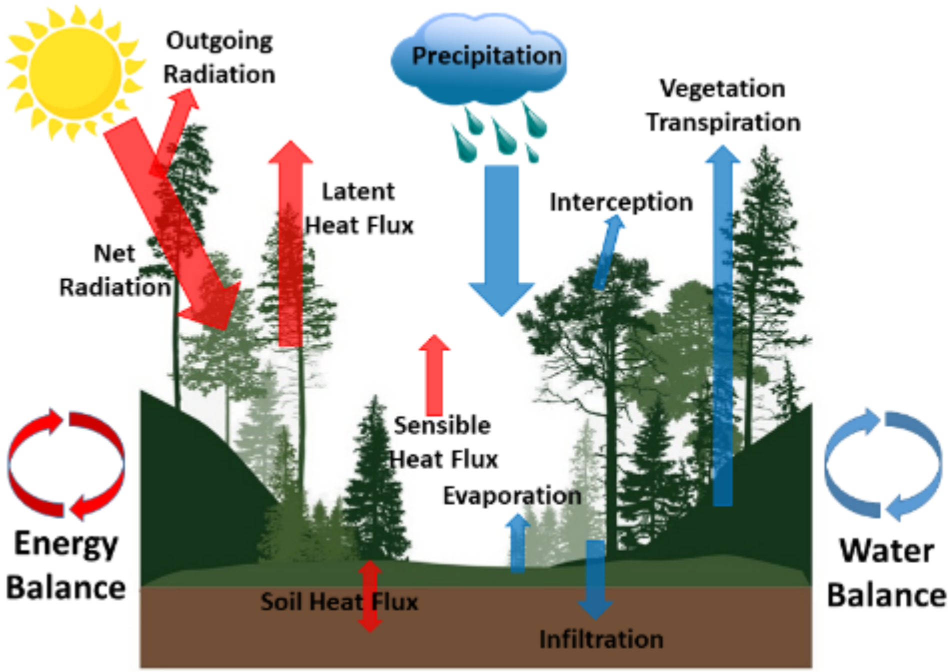
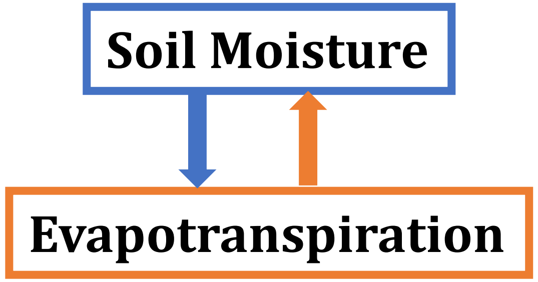
Land Science and Data Analysis

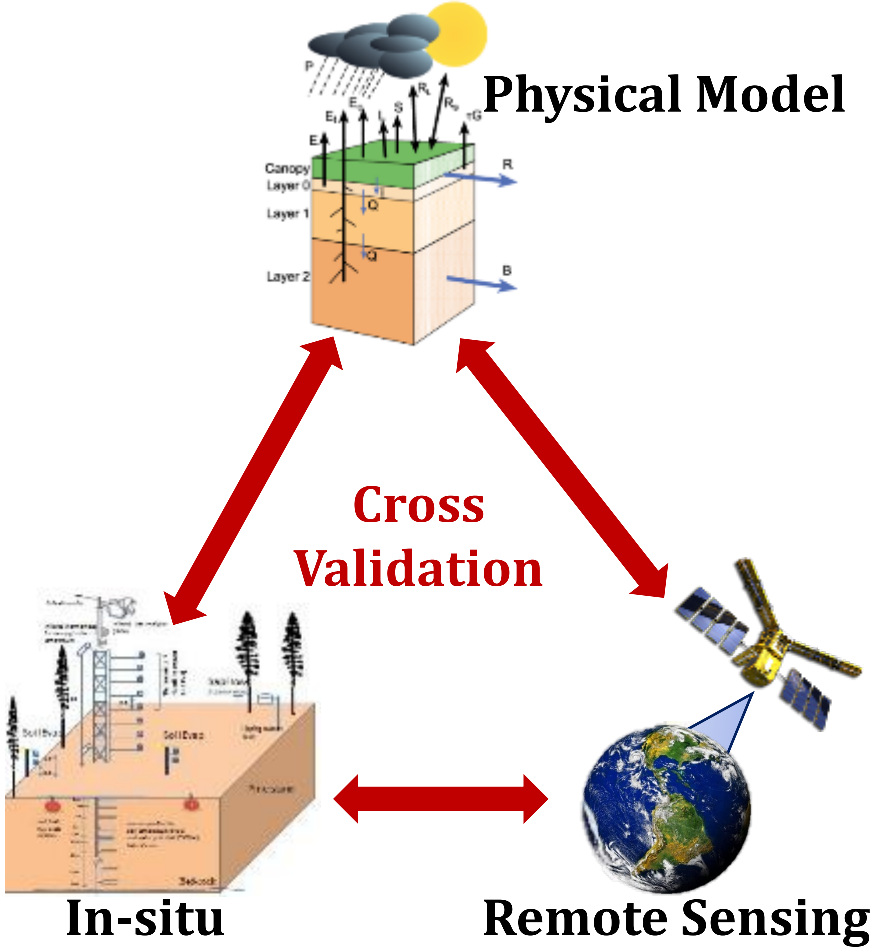
USDA
United States Department of Agriculture
Agricultural Research Service

Motivation – Water and Energy Balance Coupling

Land-Atmosphere Interaction



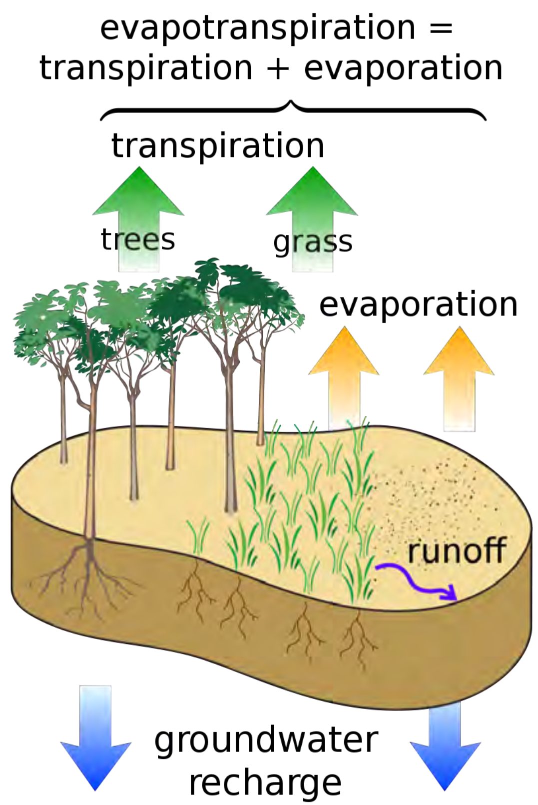




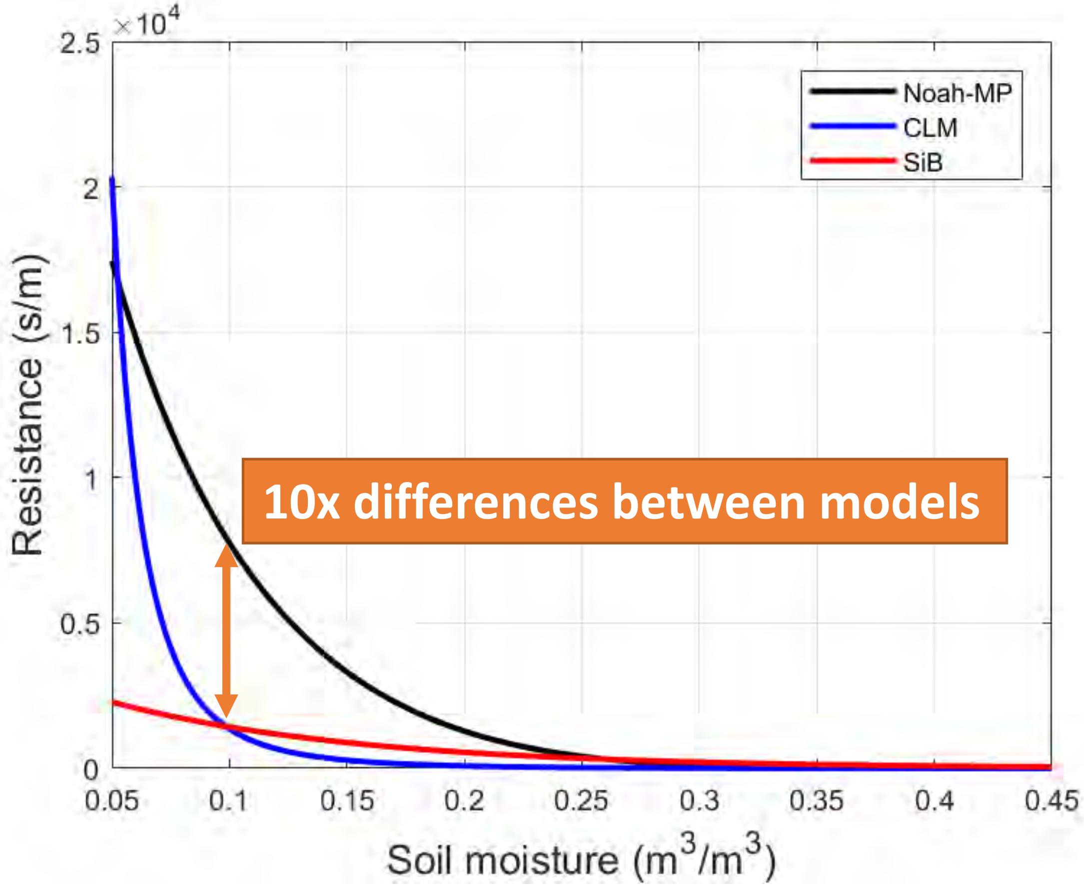
Motivation – Improving the Understanding

Here comes the question…

Are current land surface models accurate in characterizing the relations between soil moisture and evapotranspiration?



The evaporation resistance in LSMs



Motivation – Multi-Platform Remote Sensing

Opportunities and key challenges:

Coupling estimates obtained from (relatively noisy) remotely-sensed data are always biased.

MODIS Land Products

MODIS Surface Reflectance
MODIS Land Surface Temperature and Emissivity (MOD11)
MODIS Land Surface Temperature and Emissivity (MOD21)
MODIS Land Cover Products
MODIS Vegetation Index Products (NDVI and EVI)
MODIS Thermal Anomalies - Active Fires
MODIS Fraction of Photosynthetically Active Radiation (FPAR) / Leaf Area Index (LAI)
MODIS Evapotranspiration
MODIS Gross Primary Productivity (GPP) / Net Primary Productivity (NPP)
MODIS Bidirectional Reflectance Distribution Function (BRDF) / Albedo Parameter
MODIS Vegetation Continuous Fields
MODIS Water Mask
MODIS Burned Area Product

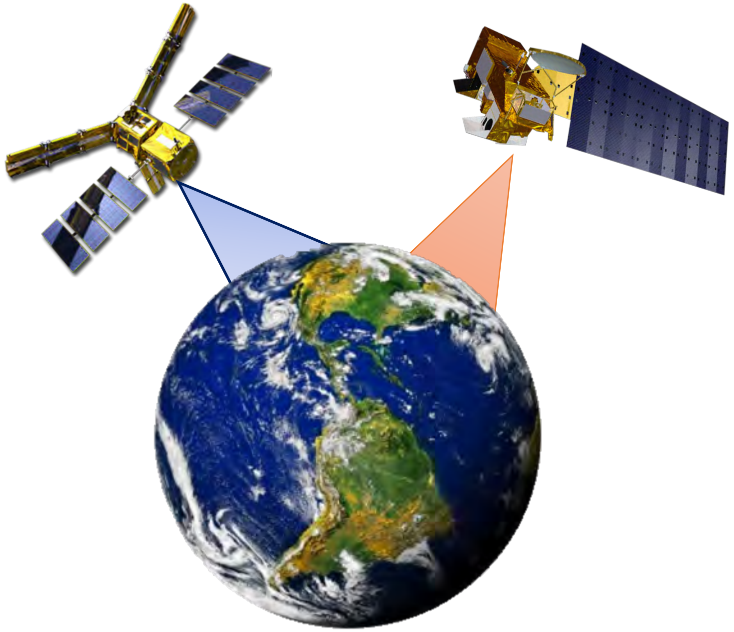
Snapshot of MODIS Land Products

Multi-platform satellite soil moisture and evapotranspiration products

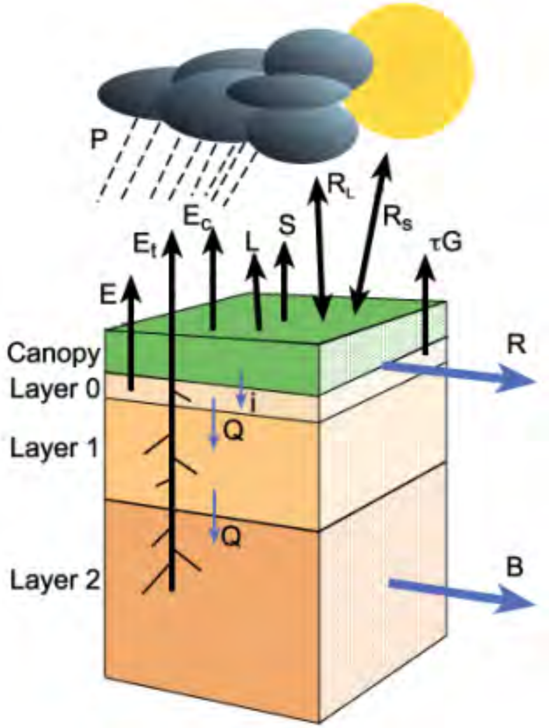
Project Objectives

Our approach:

Obtain unbiased, observation-based global estimates of true coupling by integrating multi-platform soil moisture and evapotranspiration retrievals



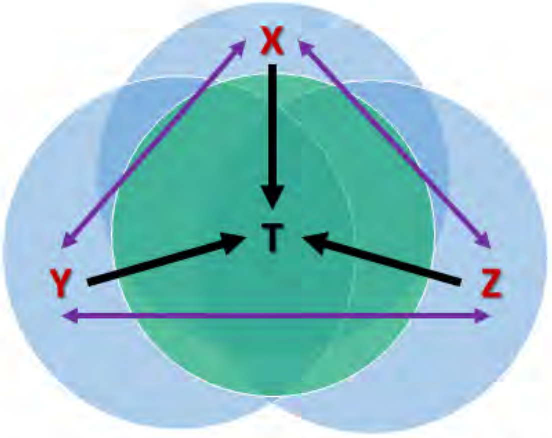
Benchmarking



A Unified Approach to Integrate Products

Triple collocation-based coupling strength metric

	Soil Moisture		Evapotranspiration
X	PASSIVE	X	ALEXI-TIR
Y	ACTIVE	Y	ALEXI-MW
Z	MODEL	Z	MODEL



Linear Model and Error Orthogonality

Mutual Random Error Independency

Soil Moisture ⟷ **Evapotranspiration**

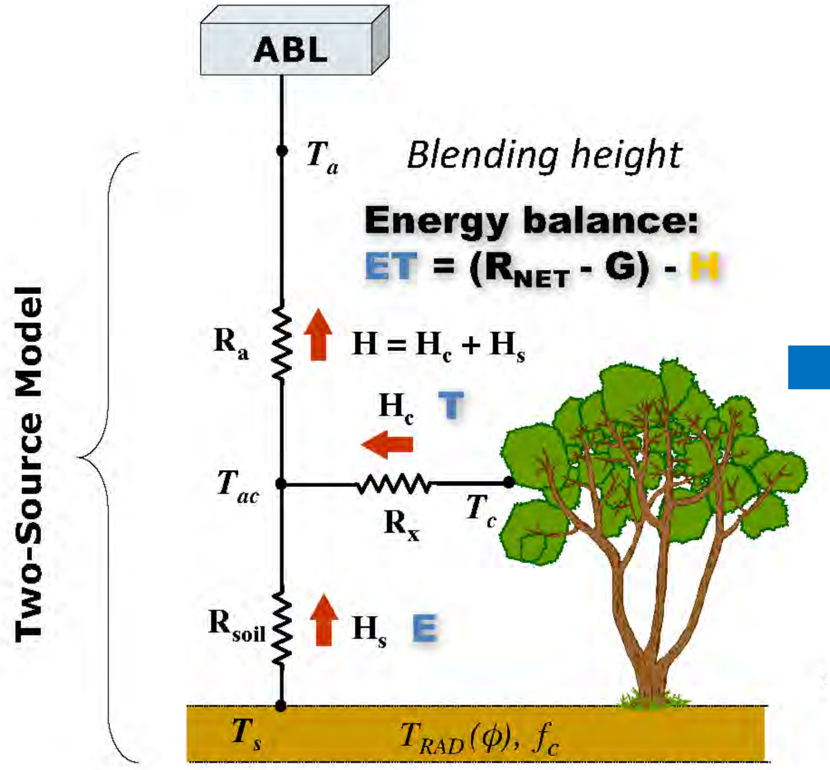
Coupling Metric

$$R^2[SM_{True}, ET_{True}]_{X,X} \equiv \frac{Cov[SM_X, ET_X]^2 Cov[SM_Y, SM_Z] Cov[ET_Y, ET_Z]}{Cov[SM_X, SM_Y] Cov[SM_X, SM_Z] Cov[ET_X, ET_Y] Cov[ET_X, ET_Z]}$$

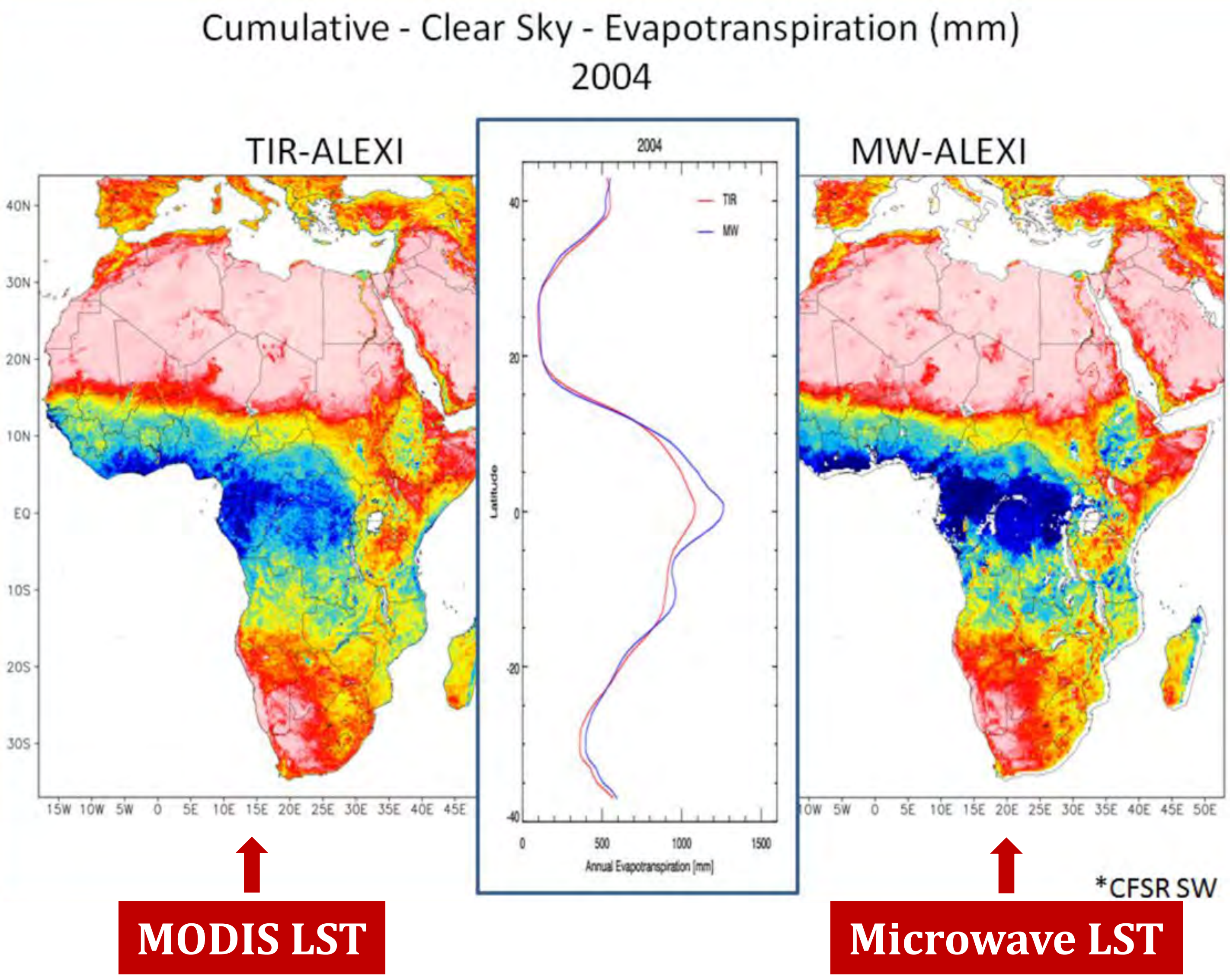
[Crow et al., 2015]

Multi-Platform Land Products – Evapotranspiration

Atmosphere-Land Exchange Inverse



ALEXI
(Atmosphere-Land Exchange Inverse model)

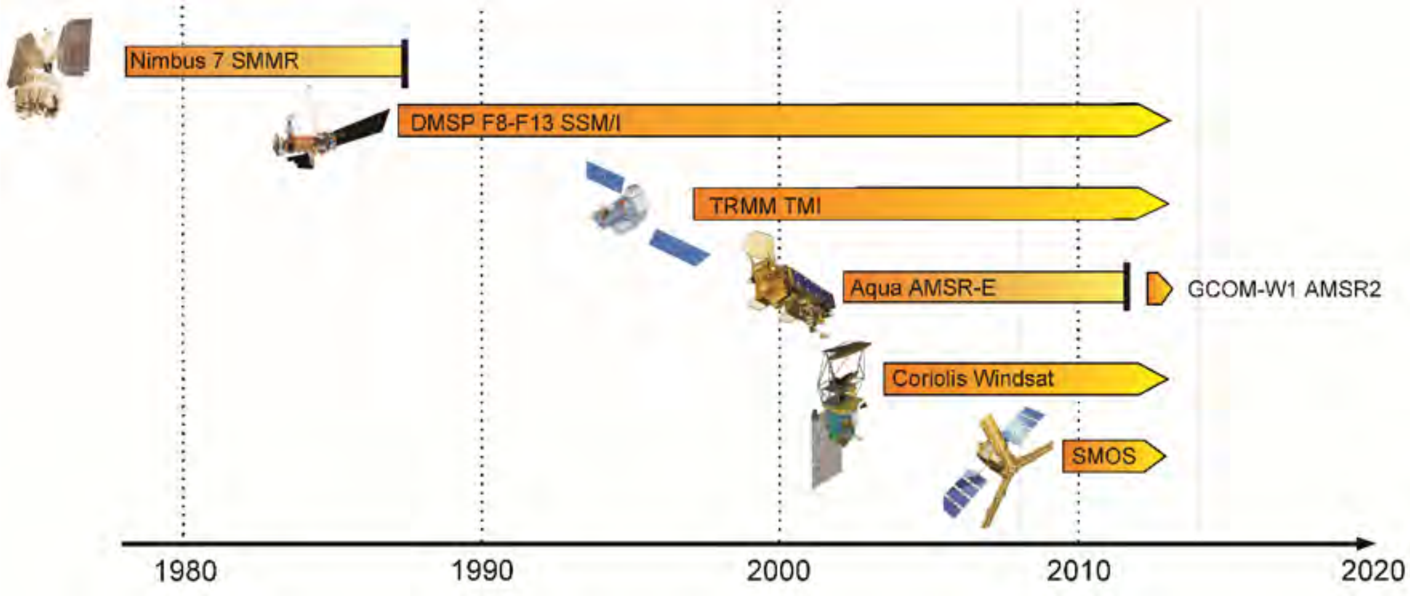


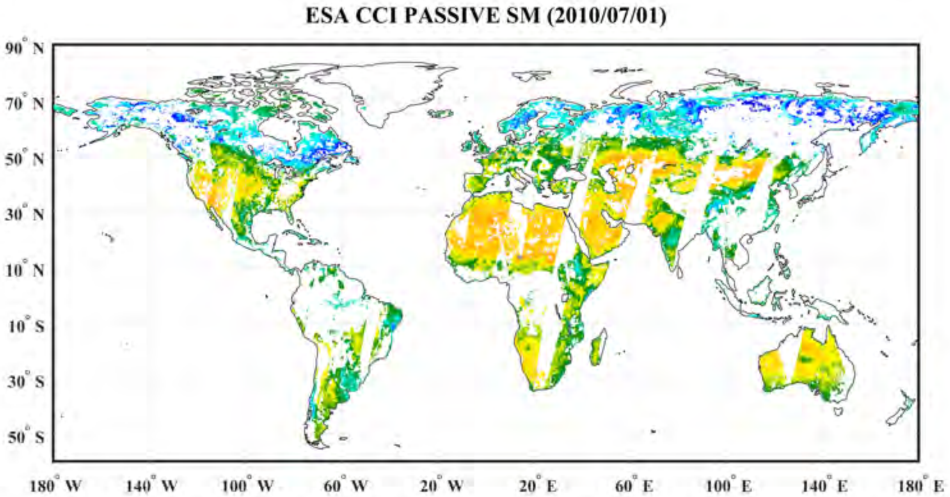
[Anderson et al., 2011]

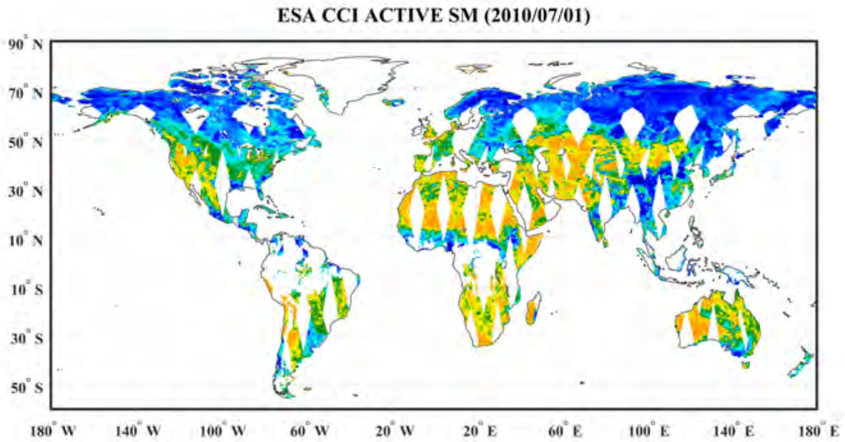
[Holmes et al., 2018]

Multi-Platform Land Products – Soil Moisture

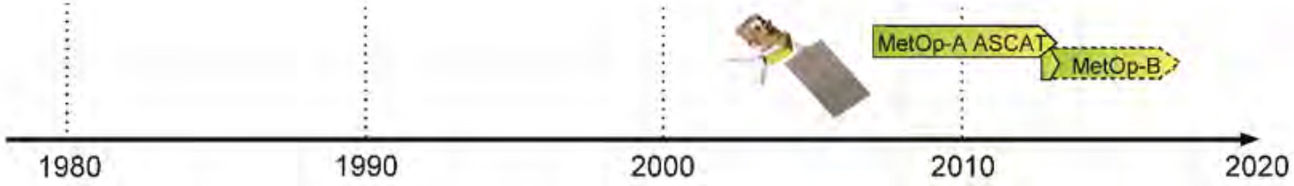
ESA CCI merged passive microwave soil moisture







MetOp-A/B ASCAT active microwave soil moisture

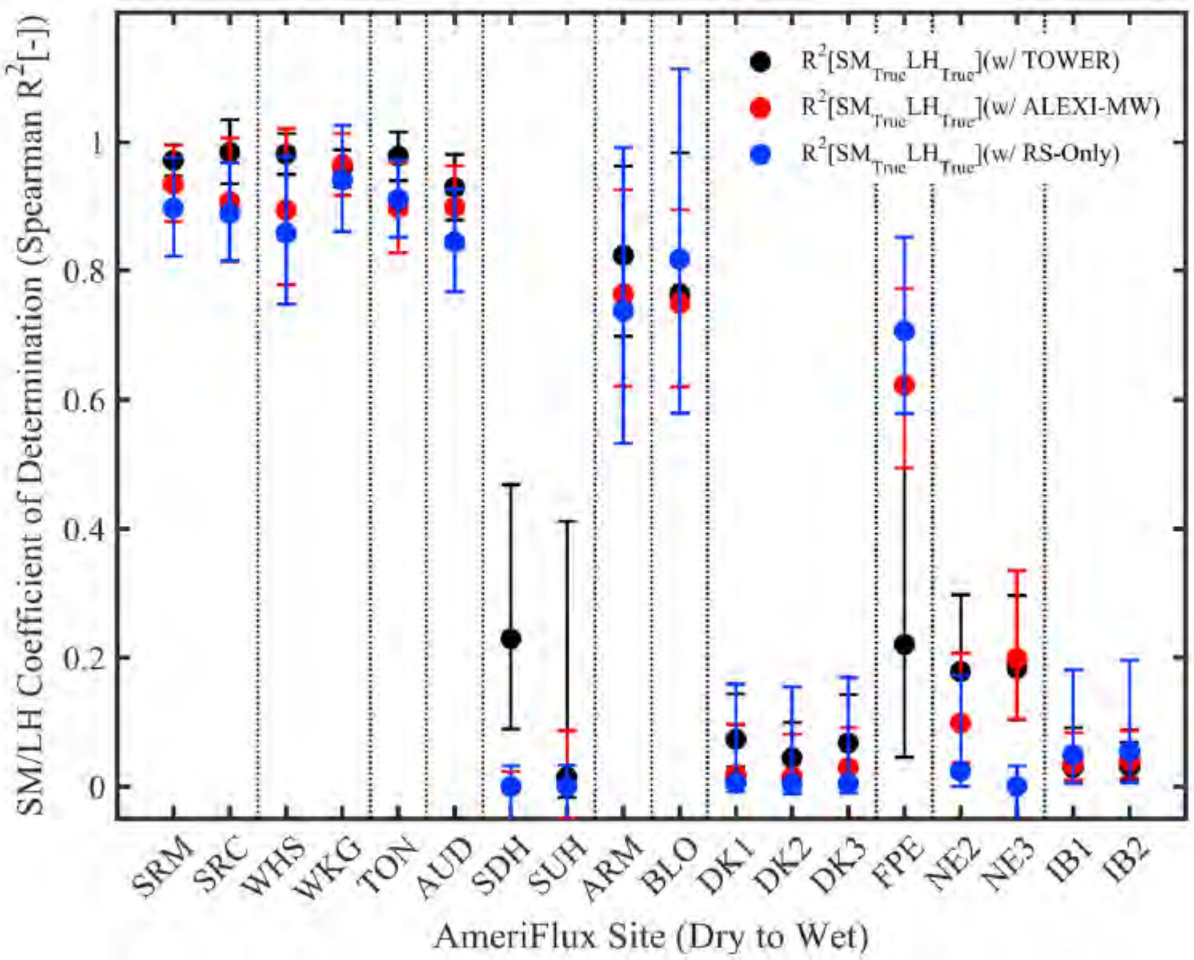


[Dorigo et al., 2017]

Verification of the Unified Approach

A list of in-situ AmeriFlux tower sites → **Verifying the applicability of RS data**

AmeriFlux Site	Abbreviation	Latitude/Longitude	SM Depth (cm)
Lucky Hills	WHS	31.744°/−110.052°	5
Kendall Grasslands	WKG	31.737°/−109.942°	5
Santa Rita Mesquite	SRM	31.821°/−110.866°	2.5
Santa Rita Creosote	SRC	31.908°/−110.840°	2.5–5
Tonzi Ranch	TON	38.432°/−120.966°	0–2.5[b]
Audubon Grasslands	AUD	31.591°/−110.509°	10
ARM-CART	ARM	36.606°/−97.489°	10[c]
Blodgett Forest	BLO	38.895°/−120.633°	10
Sand Hills Dry Valley	SDH	42.069°/−101.407°	10
Sand Hills Upland Dune[d]	SUH	42.066°/−101.367°	10
Duke Open Field	DK1	35.971°/−79.093°	10
Duke Hardwoods	DK2	35.974°/−79.100°	10
Duke Pine	DK3	35.978°/−79.094°	0–30
Fort Peck	FPE	48.308°/−105.102°	10
Mead Irrigated	NE2	41.164°/−96.470°	10
Mead Rainfed	NE3	41.180°/−96.440°	10
Fermi Agricultural	IB1	41.859°/−88.223°	2.5
Fermi Prairie	IB2	41.841°/−88.241°	2.5

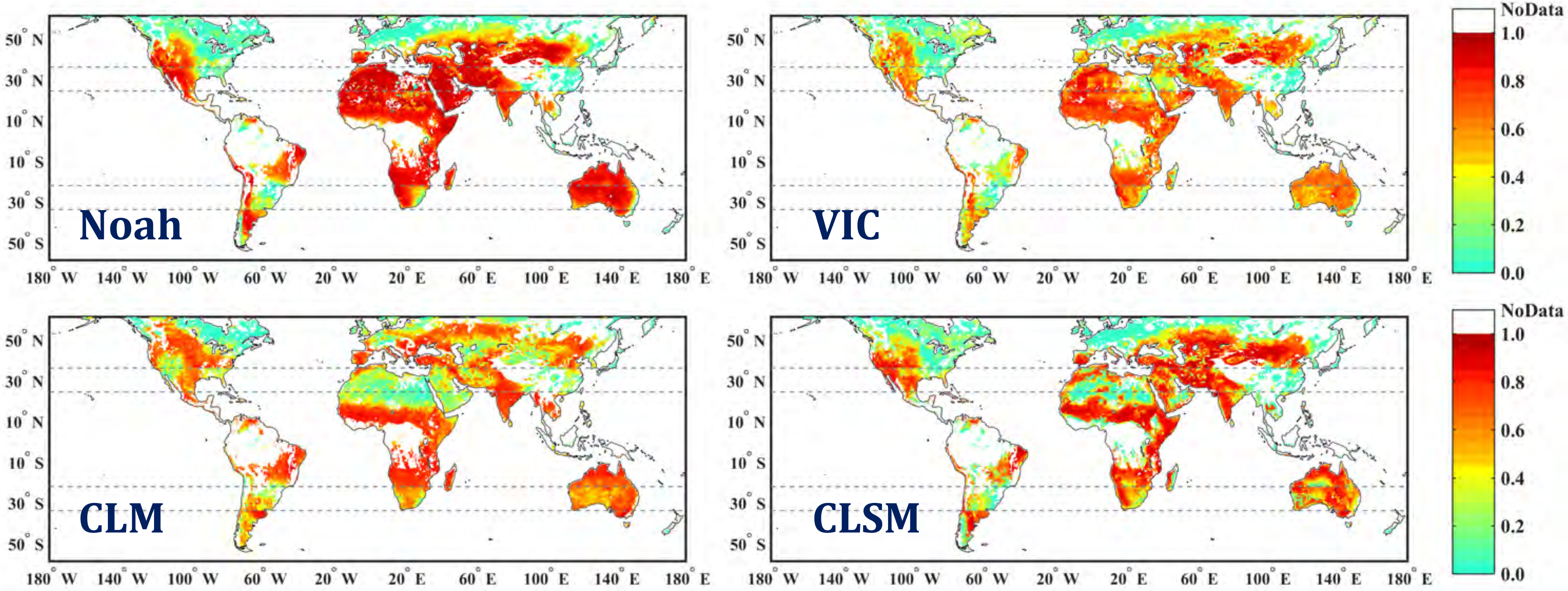


Discrepancy Among Land Surface Models

Global Land Data Assimilation System

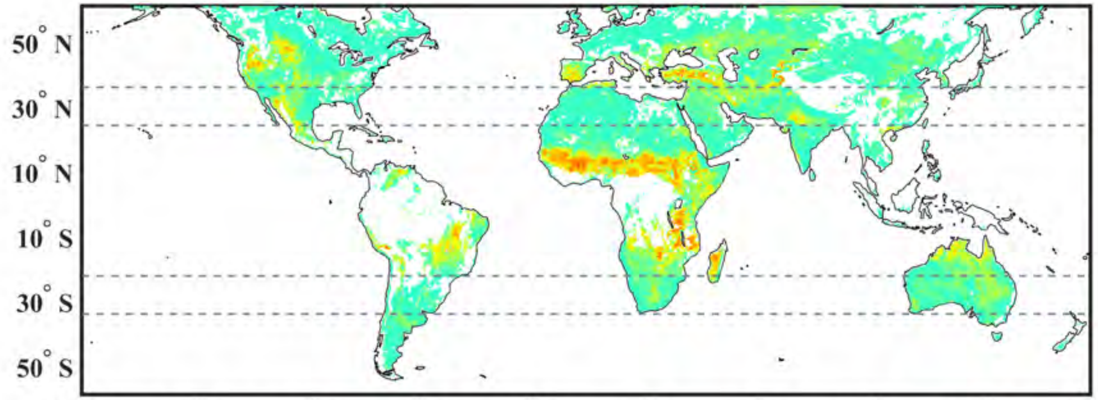
- Noah v3.3
- Community Land Model (CLM) v2.0
- Variable Infiltration Capacity (VIC)
- Catchment Land Surface Model (CLSM) F2.5

$R^2[SM_{LSM}ET_{LSM}]$

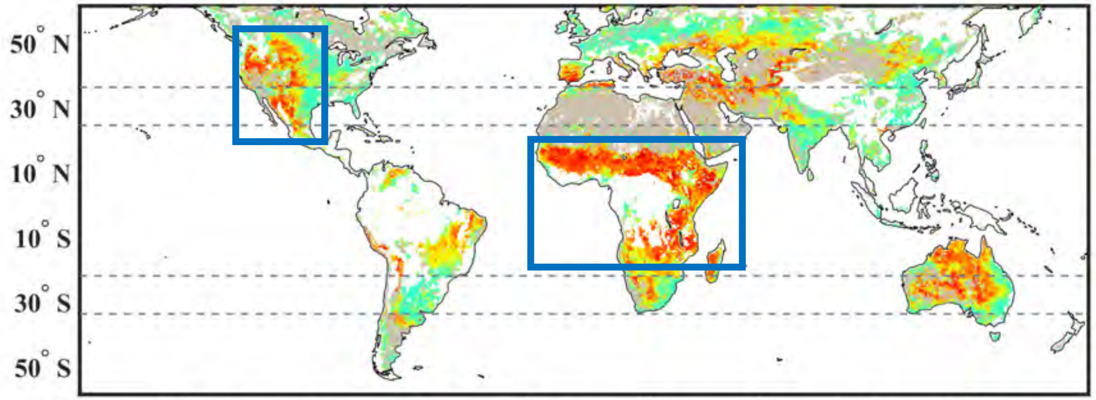


Integrated Multi-platform based Coupling Estimates

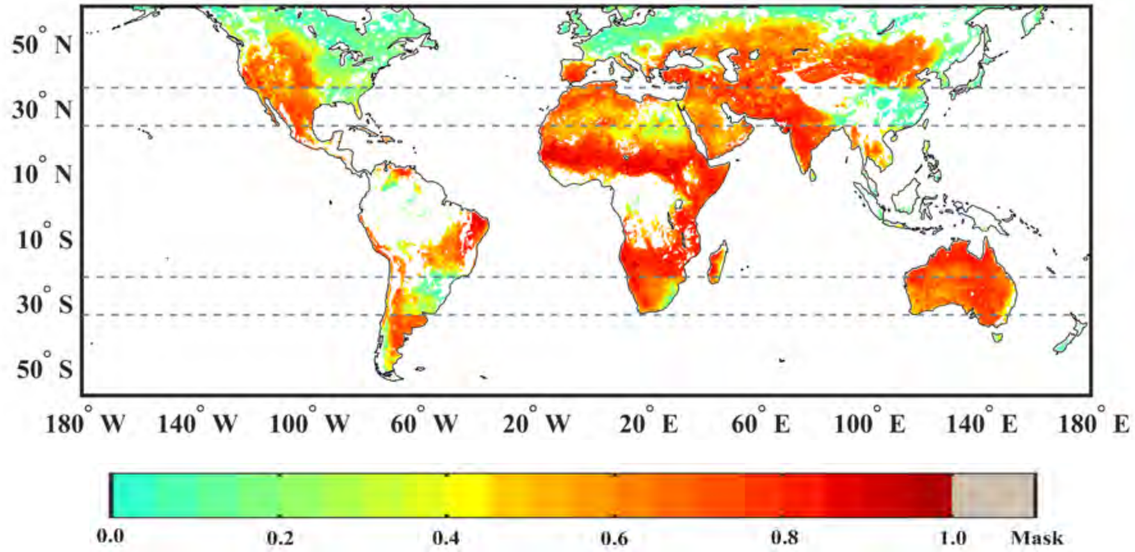
Remote Sensing $R^2[SM_{RS}ET_{RS}]$

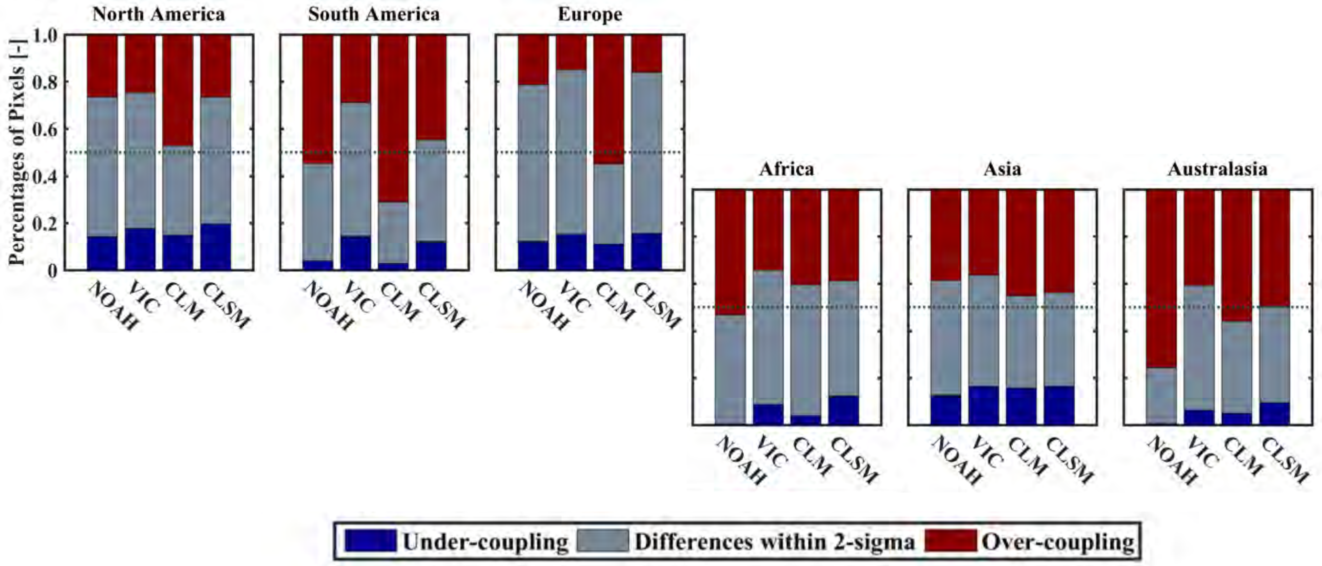


Triple Collocation $R^2[SM_{TC}ET_{TC}]$



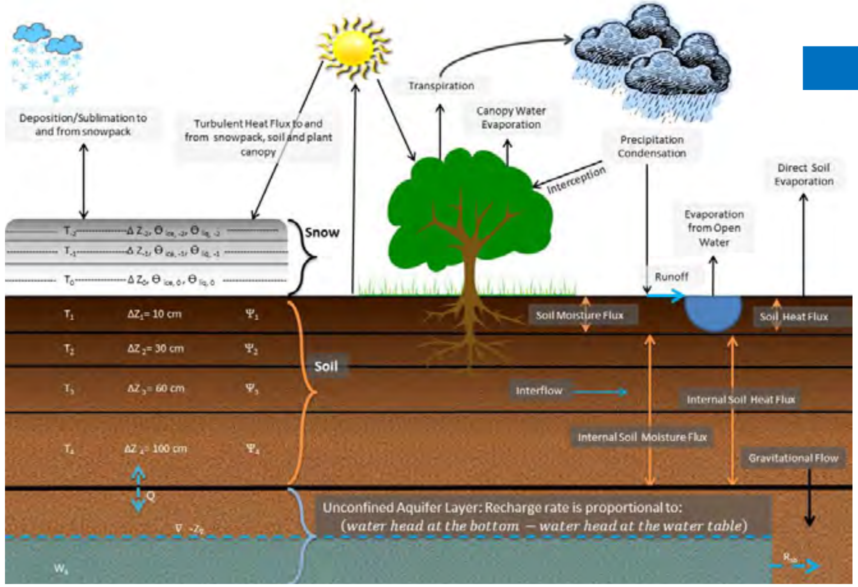
GLDAS LSMs $R^2[SM_{LSM}ET_{LSM}]$





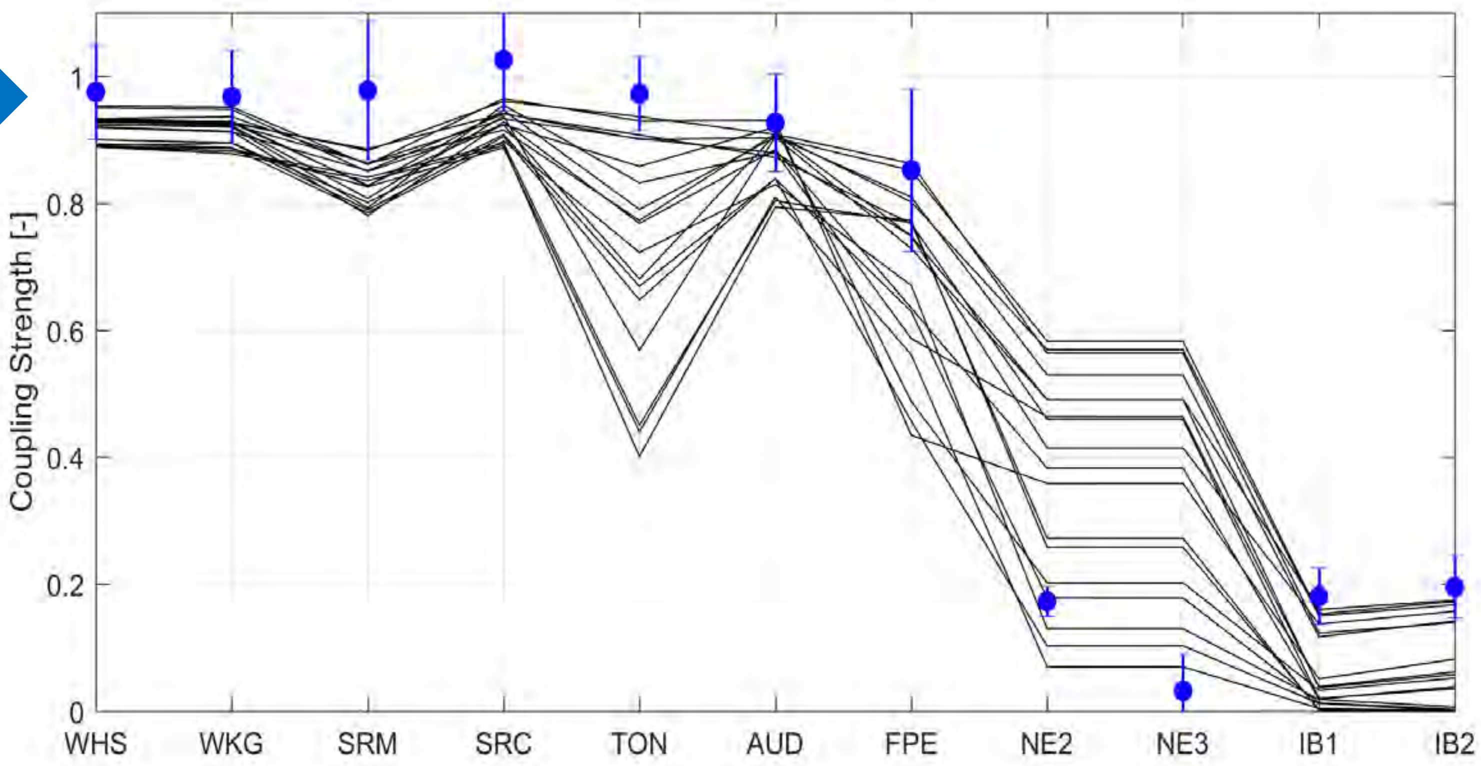
Noah-MP with Different Model Settings

Noah-MP (modular)



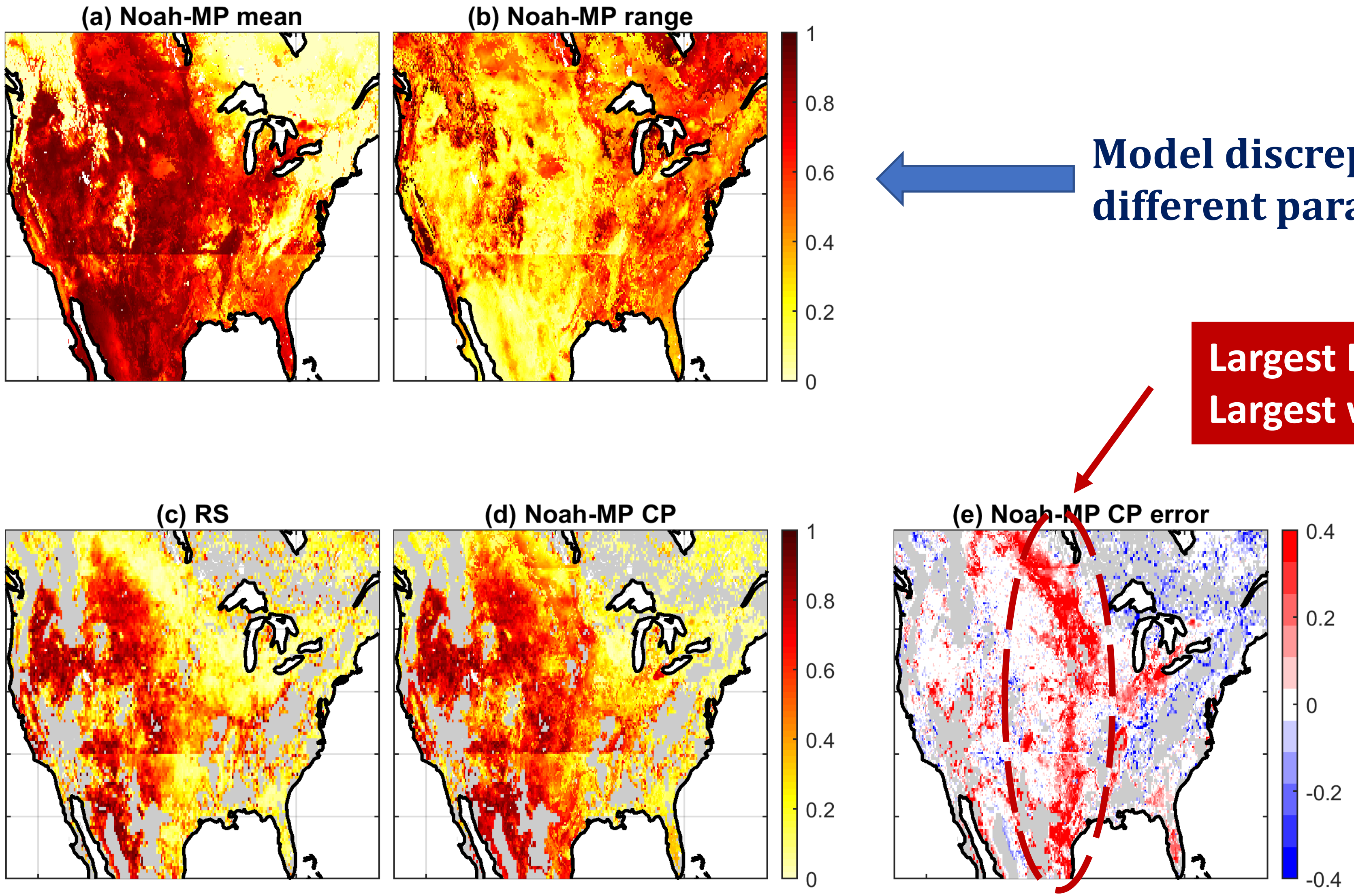
Multi-Parameterization
Multi-Physics Options

Model runs with different resistance functions



Dry → Wet

Optimizing Noah-MP over North America



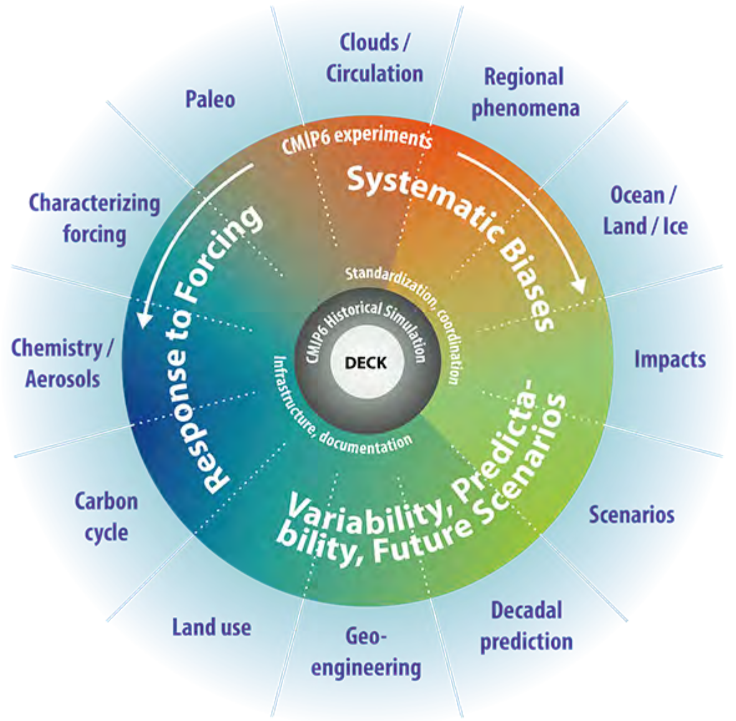
Model discrepancies generated by different parameterization schemes

Largest ET bias?
Largest weather forecasting error?

Optimizing Noah-MP

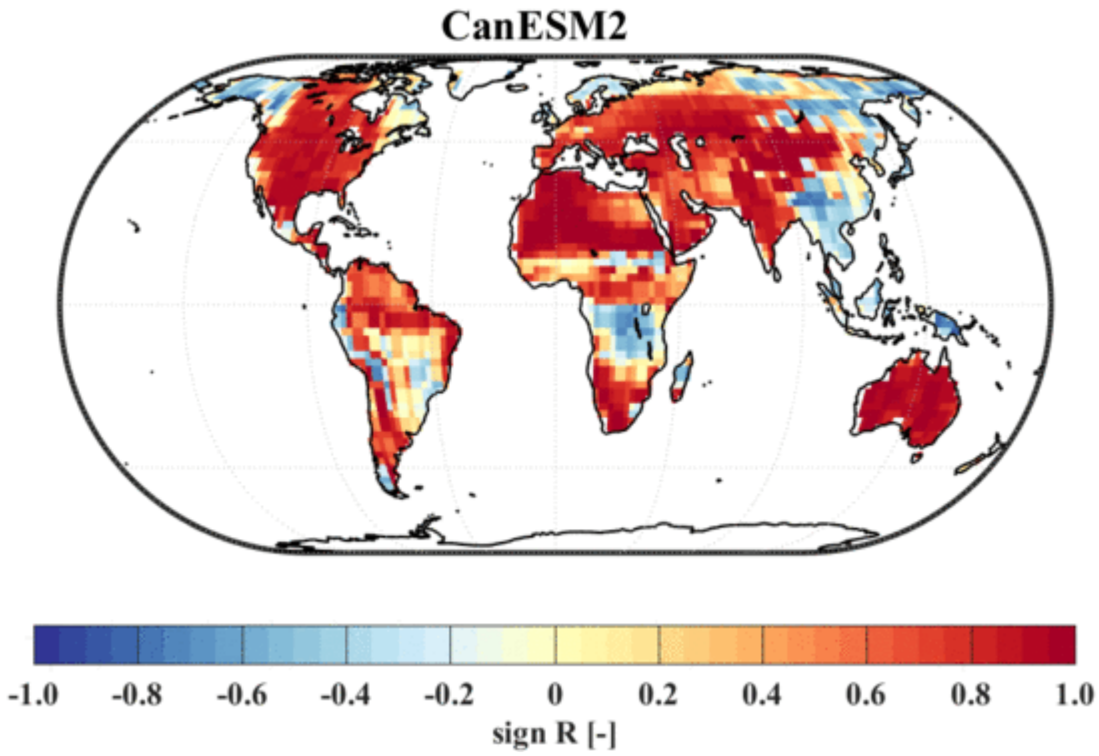
From Offline to Coupled Models

Coupled Model Intercomparison Project



WCRP CMIP5
World Climate Research Programme

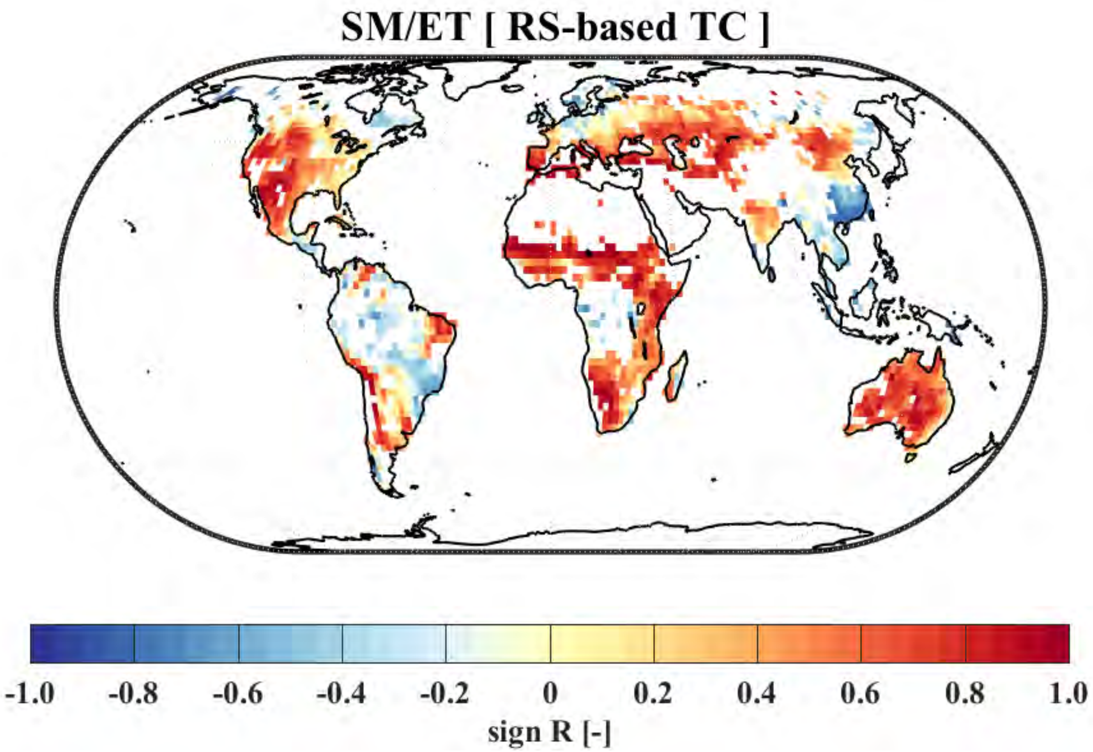
SM-ET coupling strength in models



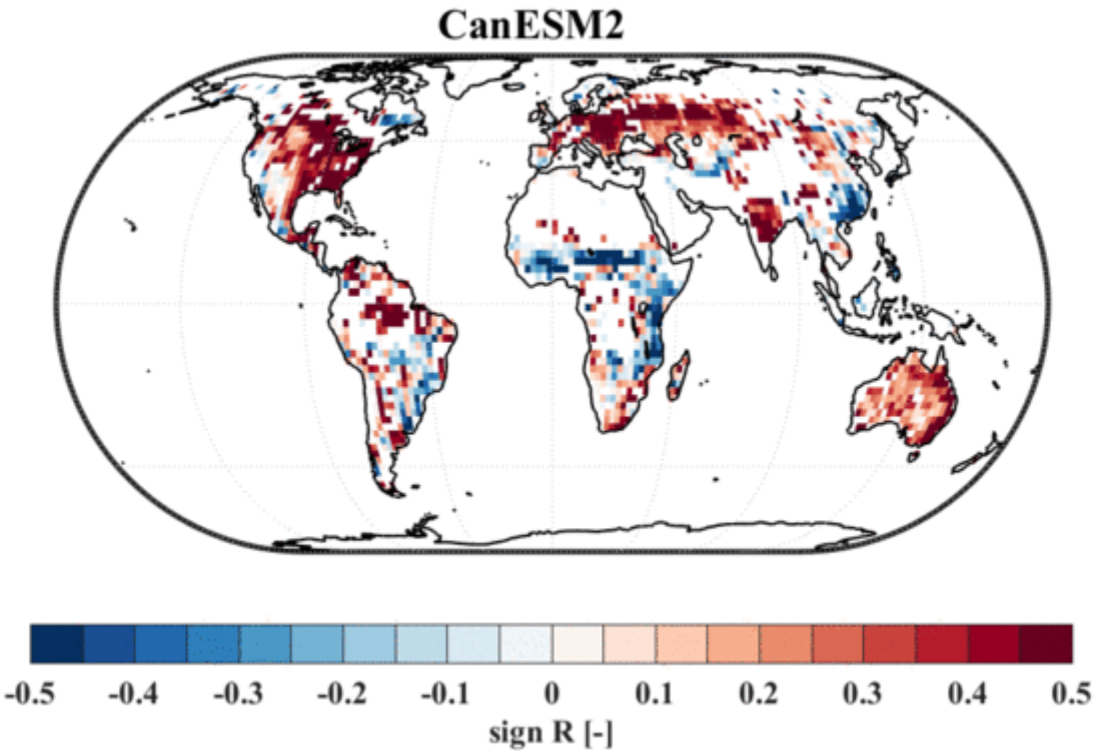
12 Coupled Global Climate Models

Contrasting Against Corrected RS-based Estimates

Triple collocation-based estimates



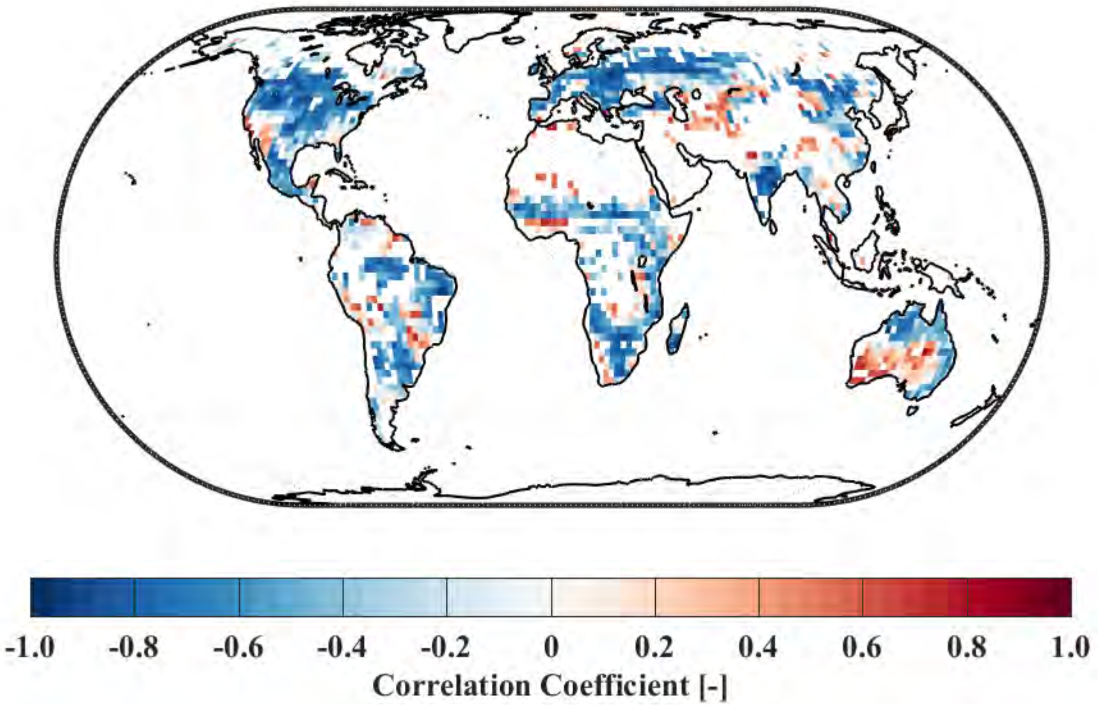
Differences between GCMs and TC estimates



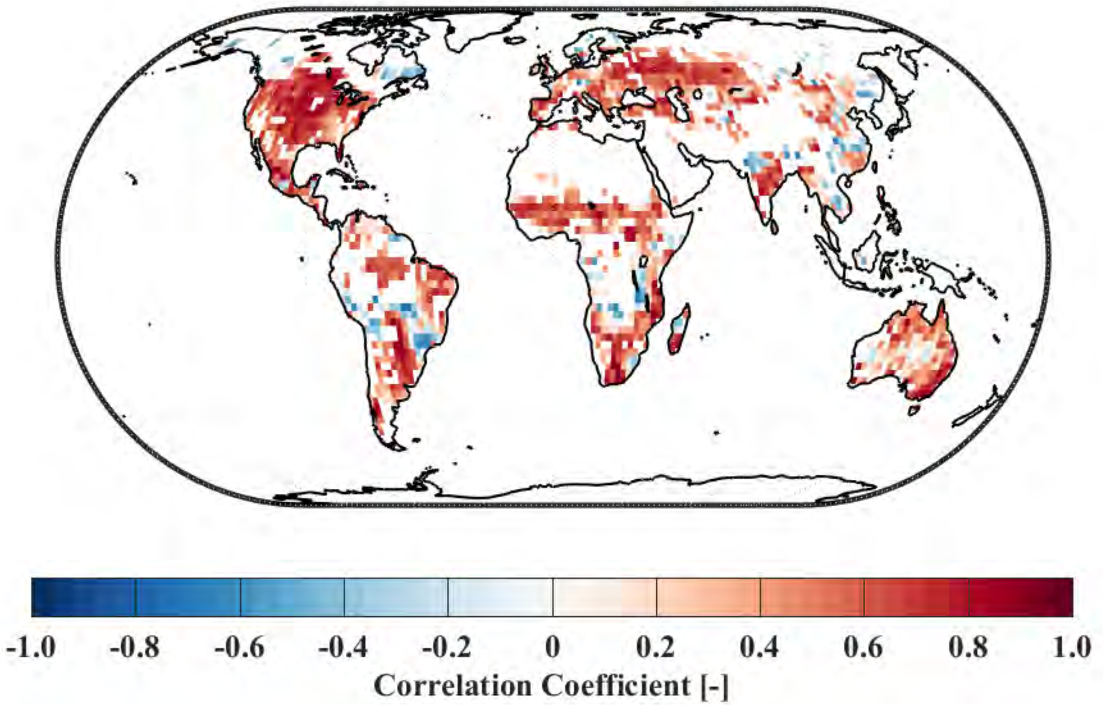
With Regard to Lower Boundary Conditions

Relationship between the biases of coupling strength and atmospheric conditions

Precipitation



Air Temperature



Note: Each grid cell value is based on 12 GCMs

Key Science Highlights

Here come the answers...

- **Offline land surface models demonstrate large discrepancies in their coupling strength between soil moisture and evapotranspiration**
- **Using corrected multi-platform based estimates, model parameterization schemes can be optimized**
- **Land surface model plays an important role in the coupled global climate models and coupling biases between soil moisture and evapotranspiration can potentially impact the climate simulation and analysis**

1. F. Lei, W. T. Crow, T. R. H. Holmes, C. Hain, M. C. Anderson (2018), Global Investigation of Soil Moisture and Latent Heat Flux Coupling Strength, Water Resources Research, doi:10.1029/2018WR023469

2. Jianzhi Dong, Wade T. Crow, Constraining land surface model structural error using remotely sensed soil moisture and evapotranspiration coupling strength, Geophysical Research Letters, in preparation.

3. Fangni Lei, Wade T. Crow, Jianzhi Dong, Investigating Land-Atmosphere Coupling Strength Biases in CMIP5 Climate Models Using Remote Sensing Data, Geophysical Research Letters, in preparation.

Thank you for your attention!

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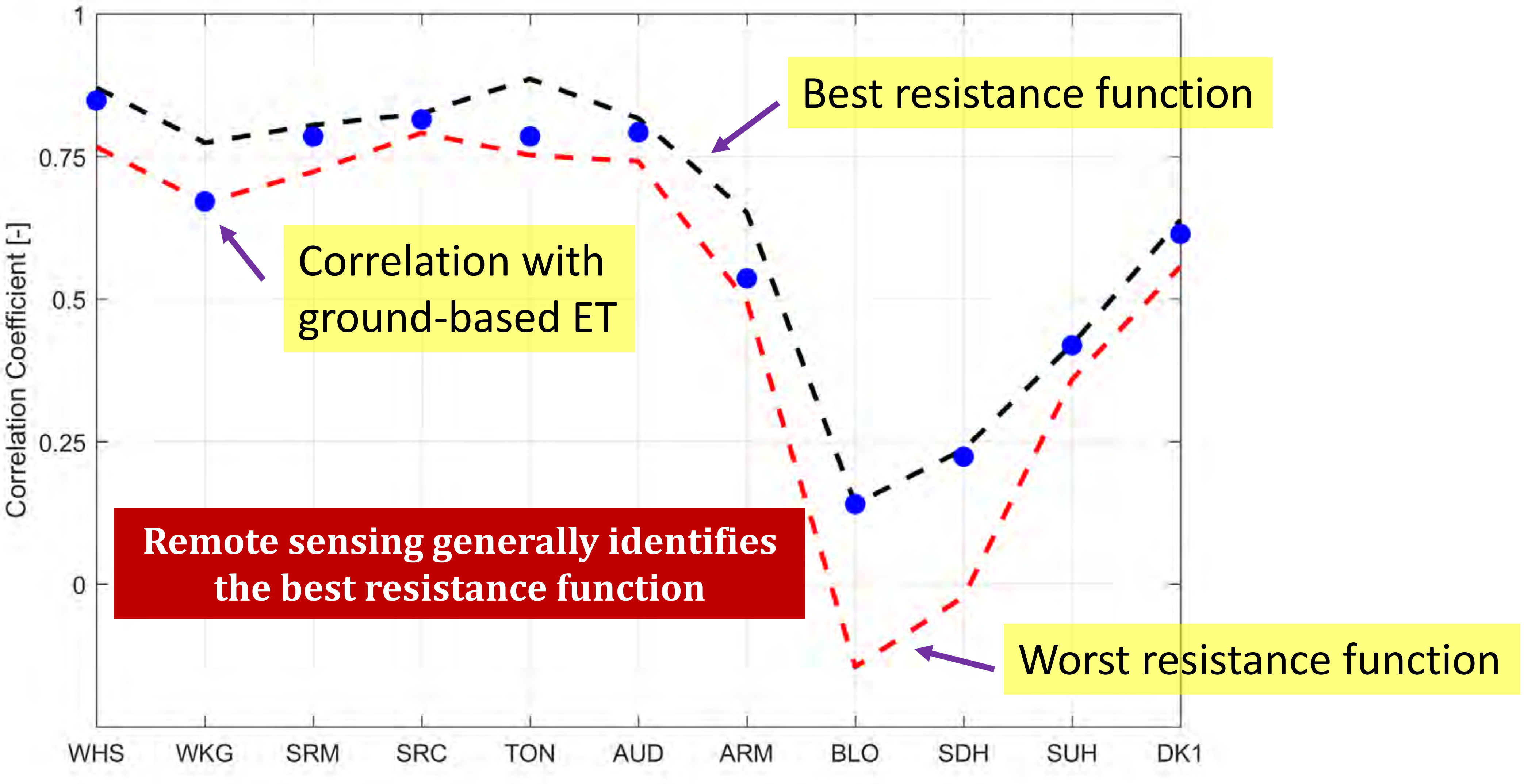
Optimizing Noah-MP over Sites

Using the corrected RS-based coupling estimates for selecting resistance function



Remote sensing generally identifies the best resistance function

Differences in Lower Boundary Conditions